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Digital Overlaying of the Universal Transverse Mercator Grid with Landsat-Data-Derived Products

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DIGITAL OVERLAYING OF THE UNIVERSAL TRANSVERSE MERCATOR GRID WITH LANDSAT-DATA-DERIVED PRODUCTS

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SUMMARY

A procedure was developed to correlate picture elements of data from the Landsat multispectral scanner with the universal tranverse Mercator grid. In the procedure, a series of computer modules is used to make approximations of universal transverse Mercator grid locations for all picture elements from the grid locations of a limited number of known control points and provide display and digital storage of the data. The software has been written in FORTRAN IV language for a Varian 70-series computer. (The original work on this procedure was developed by Thomas W. Pendleton and is available in an unpublished document (ERL Report 160) from the NASA Earth Resources Laboratory.)

INTRODUCTION

The NASA Earth Resources Laboratory (ERL), since its inception early in 1971, has been engaged in automatic processing of digital multispectral data such as those acquired by the multispectral scanners onboard the Landsat spacecraft. The processing has been performed with emphasis on automatic recognition of surface cover and on development of automatic recognition techniques. Pattern recognition techniques used at the ERL are supervised maximum-likelihood techniques based on the assumption of normally distributed multispectral data. The result of applying these pattern recognition techniques to Landsat scanner data is a classification of each picture element (pixel) of multispectral data as a particular type of surface cover or as an unknown type of surface cover.

It was recognized at the ERL that the full usefulness of the pixel-by-pixel classification would not be realized unless the classification could be related to a geographic coordinate system, such as latitude and longitude or northings and eastings. It was further recognized that the ability to update files of geographically referenced surface classifications would also be desirable, particularly in considering the repetitious nature of the Landsat coverage and the potential for gaps in the coverage because of concealing cloud cover.

The immediate circumstance that led to the development of the current set of software, which is used to create files of Landsat-data-derived geographically referenced surface classifications, was a request from the U.S. Army Corps of Engineers regarding use of remotely acquired data, especially Landsat

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multispectral scanner (MSS) data, in updating environmental information. This document is written as a guide to the techniques used in keying Landsat-data-derived surface classifications to the 1:250 000-scale V502-series maps prepared by the U.S. Army Map Service and as partial documentation of the software developed to implement the necessary techniques.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Systeme International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

TRANSVERSE MERCATOR PROJECTION AND GRID SYSTEM

The 1:250 000-scale V502-series maps distributed by the U.S. Geological Survey, Department of the Interior, are based on the transverse Mercator projection. A map projection is a representation on a plane (flat) surface of the meridians of longitude and the parallels of latitude that are defined on the Earth spheroid surface. The transverse Mercator projection is not a geometric projection, but an approximation of the projection can be visualized by considering a cylinder wrapped around a sphere that approximates the Earth spheroid. The cylinder is wrapped around the sphere so that the cylinder is tangent to the north and south poles of the sphere. Then, of course, the cylinder is tangent to a great circle that passes through the poles. This great circle is by definition a meridian of longitude. The meridians and parallels on the sphere are projected from the center of the sphere onto the tangent cylinder. The cylinder is unrolled onto a flat surface. The resulting pattern of meridians and parallels is a transverse Mercator projection the central meridian of which is the meridian of tangency.

It is evident that the Earth surface, as represented on the transverse Mercator projection, is less distorted near the central meridian and more distorted away from the central meridian. As a consequence, starting at the 180° meridian and moving eastward, the Earth spheroid is divided in bands of longitude 6° wide. The transverse Mercator projection used for each band in the V502-series maps is based on a central meridian, which is located at the center of each band. For example, in the Central United States, the V502-series maps are published on projections with central meridians at 87°, 93°, and 99° west longitude. The V502-series maps are published on sheets that cover 2° in longitude by 1° in latitude. Hence, the 6° band with central meridian at 93° west longitude, for example, consists of three sheets for each 1° band of latitude; the central meridian lies in the center of the middle sheet. At 90° west longitude, the projection changes to one based on a central meridian at 87° west longitude, and, of course, the projections do not agree at 90° west longitude.

Associated with the transverse Mercator projection between 80° south latitude and 84° north latitude is a square, or Cartesian, grid, called the universal transverse Mercator (UTM) grid. Each of the 6° bands of longitude, previously described, is sequentially numbered eastwardly from 180°. The 6° bands are then regarded as numbered grid zones. For each grid zone, a Cartesian grid is defined on the transverse Mercator projection as follows. The central meridian of the zone, which is a straight vertical (north-south) line on the projection, is the vertical axis of the grid and is artificially assigned the value 500 000 meters, so that the origin of the grid lies 500 000 meters west of the central meridian and outside the 6° grid zone in question. Distances measured in meters west to east from the origin are called "eastings" and (by construction) are always positive. The Equator, which is a straight horizontal (east-west) line on the projection, is the abscissa of the grid system in the Northern Hemisphere; and distances measured in meters south to north are called "northings." In the Southern Hemisphere, the Equator is artificially assigned a value of 10 000 000 meters and the grid system decreases toward the South Pole. On most V502-series maps, the UTM grid is shown at 10 000-meter intervals.

LANDSAT DATA GRID

Landsat multispectral data are collected by the four-spectral-band line scanner carried on the Landsat spacecraft, which are in near-circular, near-polar orbits. The orbital parameters are approximately the following (ref. 1):

Semimajor axis	7285.82 kilometers
Inclination	99.114°
Eccentricity	0.0006
Altitude	~925 kilometers

The scanner uses an oscillating mirror to scan in a direction perpendicular to the spacecraft heading. Over the United States, the spacecraft is traveling toward the Equator during data collection, and as the mirror oscillates, the data are collected in a west-to-east direction. Six lines of data are acquired simultaneously in each of the four spectral bands during each mirror sweep. The mirror sweeps at a rate such that the spacecraft velocity moves the scanner along track a distance corresponding to the width of the six scan lines acquired during each mirror sweep. The instantaneous field of view of each detector is 79 meters when the satellite is at nominal altitude, and the sample rate provides for a sample every 56 meters across track. Hence, oversampling occurs across track, and approximately contiguous coverage occurs along track. The ±2.89° oscillation of the scanning mirror results in an 11.56° field of view, or, at nominal altitude, a 185.2-kilometer (100-nautical mile) ground distance corresponding to each scan line.

The ERL uses Landsat system-corrected MSS computer-compatible tapes for pattern recognition. These tapes are described in detail in reference 2. One Landsat scene of approximately 185.2 by 185.2 kilometers (100 by 100 nautical miles) consists of 2340 scan lines and either 3240 elements per line (Landsat 1) or 3264 elements per line (Landsat 2). A Landsat scene is stored on four computer-compatible tapes. Historically, the first tape has contained the first 810 or 816 elements of each scan line, the second tape the next 810 or 816, the third tape the next 810 or 816, and the fourth tape the remaining elements.

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With respect to UTM coordinates, the finite scan time causes offsets in the easterly direction, and the rotation of the Earth causes offsets in the westerly direction. By shifting each successive set of six scan lines to compensate for skewness, one can better model the groundtrack of the spacecraft over the region to be mapped as a straight line.

The ground distances between line elements are not equal basically because of two factors. The first factor will be referred to as the "tangent effect," and the second factor will be referred to as the "mirror velocity effect."

The tangent effect is illustrated by figure 2. If it is assumed that the MSS takes samples at equal angles, then the ground distances between successive elements near the ends of the scan line are greater than ground distances between successive elements near the center of the scan line.

The mirror velocity effect is caused by the speeding up and slowing down of the mirror during the MSS scan of the ground. This effect is described in reference 2. In an effort to model the mirror velocity effect, the ERL conducted several experiments in which numerous control points for one Landsat frame were chosen from 1:2400-scale maps whenever 1:2400-scale maps existed for the region under consideration. (The following section includes a detailed discussion of control points.) A graphical result of one such experiment is illustrated in figure 3, in which 133 control points were used. Figure 3(a) shows the residual errors of mapped elements with respect to their element number after the errors due to skew and tangent effects were corrected. Correcting for the mirror velocity effect using some type of interpolation would probably not be satisfactory because it would increase the number of computer operations by a factor of several million, and the increased data processing time would detract from the intended simplicity of the ERL technique. Therefore, a trigonometric function was chosen to approximate the mirror velocity effect. Figure 3(b) shows the residual errors of mapped elements with respect to their element numbers after the trigonometric correction for the mirror velocity effect. Tables I to III list the control points and the mapped control points before and after the mirror velocity has been corrected; the ERL has found that, if uncorrected, the mirror velocity effect can introduce as much as a 90-meter root-mean-square (rms) error.

After corrections for skew, the tangent effect, and the mirror velocity effect have been applied, the scan line number and corrected element number can be modeled as linear functions of eastings and northings. The mapping formulas then take the form

$$XL = A_1 + A_2E + A_3N \tag{1}$$

$$XE = B_1 + B_2E + B_3N \tag{2}$$

where the A_i's and the B_i's are the mapping formula coefficients that must be determined for each application as indicated in the next section; E and N are eastings and northings, respectively, in 50-meter units; XE and XL are, respectively, the Landsat-corrected element number and scan line number.

Motivation for the formulation can be found using figure 4 as a guide. In figure 4, (E_c, N_c) is a given easting and northing on the groundtrack which corresponds to a scan line and corrected element, say XL_c and XE_c, respectively. Further, (E,N) is a given easting and northing in the Landsat scene for which the corresponding scan line and corrected element, XL and XE, respectively, are to be determined. Finally, I is the distance on the ground between successive Landsat scan lines, and J is the distance on the ground between successive corrected Landsat line elements. From figure 4,

$$[N_c - (XL - XL_c)I \sin i] - N = \tan mu \left\{E - [E_c - (XL - XL_c)I \cos i]\right\} \quad (3)$$

$$E - [E_c - (XL - XL_c)I \cos i] = \cos mu(XE - XE_c)J \quad (4)$$

Because the terms N_c, XL_c, I, J, i, mu, and E_c are taken as constant, equation (3) can be reduced to equation (1) by algebraic manipulation; and, likewise, by eliminating the $(XL - XL_c)$ terms in equation (4) by using equation (3), equation (4) can be reduced to equation (2).

For the mapping formulas to be valid, new mapping coefficients should be computed for approximately each 1° by 1° region to be mapped. The accuracy of the mapping coefficients is largely dependent upon the choice of control points. The relationship between control points and mapping accuracy is examined in the following section.

DETERMINATION OF PARAMETERS

As indicated previously, the mapping coefficients, A_i's and B_i's in equations (1) and (2), must be determined for each application. A unique set of mapping coefficients must be determined for each Landsat frame and for each UTM grid zone. For evenly dispersed control points, applications to date have shown that mapping accuracy depends upon the accuracy with which the control points are chosen and upon the number of control points used in computing the coefficients.

A control point is the northing and easting on the Earth surface of a place the image of which can be located in the Landsat data and matched to scan line and element of the image in the Landsat data. At the ERL, control points are selected using various scale maps and color CRT cursor-equipped display devices to mark a particular pixel. The CRT display devices have electronic readouts that indicate the scan line and element of the pixel marked. These devices are driven by the PSUTAP's generated by the ERL pattern recognition system as indicated in the section entitled "Landsat Data Grid." It is, of course, possible to pick control points using the color-coded classification PSUTAP's, but this procedure is not generally desirable because of the lack of resolution.

Care in control point selection is critical in obtaining accurate mapping results. It is very important to select control points that can be readily identified, such as intersections of roads and railroads and points where bridges cross streams. Care should be taken not to select features that tend to change position as a function of time, such as river bends and field boundaries. Furthermore, features that are easily identified in the display of the Landsat data should be selected. If control points are picked from 1:250 000-scale maps, 0.05 centimeter (0.02 inch), the historical cartographic manual plotting standard, is equivalent to 127 meters.

In one experiment, the UTM coordinates of 23 control points were determined using a 1:250 000-scale map, and the UTM coordinates of the same 23 points were determined using 1:24 000-scale maps. In both cases, the northings and eastings were derived using an ALTEK digitizer. A listing from that test case is shown in tables IV and V. It should be noted that the rms error of the mapped control points picked from the 1:250 000-scale map is 39 meters greater than the rms error of the mapped control points picked from the 1:24 000-scale maps. Similar experiments yielded essentially the same result; that is, control points picked from maps with scales less than 1:250 000 give rise to smaller mapping errors than control points picked from 1:250 000-scale maps because of the respective inherent map errors.

The number of control points required to produce an accurate map is difficult to define precisely. Because there are six unknown mapping coefficients in equations (1) and (2); algebraically, three points are all that are necessary to solve for the coefficients. However, applications have shown that more than three points are essential to produce good mapping accuracy. As one would expect, the accuracy of the mapping varies directly as the number of accurate control points used to compute the mapping coefficients. Twenty evenly dispersed and accurate control points for a 1° by 1° region should assure mapping accuracy with an rms error no greater than 100 meters.

Because it is not possible to choose control points coordinates without error and because the mapping formulas do not exactly model the Landsat geometry, a least-squares technique is used to estimate the mapping coefficients. Assume M control points chosen as previously described and defined by

$$\left\{N_i, E_i, XL_i, XE_i\right\}_{i=1}^{M}$$

where i is a positive integer, and consider equations (1) and (2) cast in the following form.

$$XL \cong A_1 + A_2E + A_3N \tag{5}$$

$$XE \cong B_1 + B_2E + B_3N \tag{6}$$

Then, consider the two sums

$$\sum_{i=1}^{M} [XL_i - (A_1 + A_2E_i + A_3N_i)]^2 \tag{7}$$

$$\sum_{i=1}^{M} [XE_i - (B_1 + B_2E_i + B_3N_i)]^2 \tag{8}$$

The unknown coefficients, A_i's and B_i's are chosen to make the sums a minimum using elementary calculus; that is, the equations are differentiated with respect to the six unknowns. The resulting six equations in the six unknowns are set equal to zero and solved simultaneously. The values obtained for A_i's and B_i's are then used as the coefficients in the mapping formulas for the application at hand.

Synopsis of Each Software Module

The software used for keying Landsat-data-derived products to the V502-series maps consists of three modules (appendix B, fig. B-1). Two of these modules, CONSTANTS and GEOREF, are required to produce an output file in the RMD-disk file containing the geographically referenced data. The other module, FILE COPY, serves various other auxiliary purposes as described in the following paragraphs. The software modules are written in FORTRAN IV language. The modules operate on a Varian 70-series computer functioning under Vortex II and operate on other systems as described in reference 3.

Each module requires a line printer and a card reader. The GEOREF and FILE COPY modules require a tape drive and a disk that can contain 20 700 blocks of 120 words (16 bits) each. The disk is for storage of the geographically referenced data corresponding to 100 000 meters east-west by 115 000 meters north-south. An additional requirement is a display device that can be driven by a PSUTAP and that creates a display suitable for determining the Landsat scan-line and element numbers of control points. Such a display device would also be used for editing and inspecting final products.

Those interested in running the PATREC program on their own computer should acquire the program and the associated documentation from COSMIC, the NASA software dissemination facility. The address is Computer Software Management and Information Center, Suite 112, Barrow Hall, University of Georgia, Athens, Georgia 30601.

For inputs and directives to the CONSTANTS and GEOREF modules, the ERL uses a remote terminal that operates under an interactive, time-sharing system. However, the use of a remote terminal is optional.

The CONSTANTS module, (appendix B, fig. B-2), which requires 23 252 octal (9898 decimal) words (16 bit) of storage, accepts an arbitrary number (greater than 3) of control points as input. These control points are used to determine the mapping coefficients in equations (1) and (2) as described in the preceding section. The mapping coefficients are then used with the northing and easting of each control point in the right side of equations (1) and (2) to compute the predicted scan-line and element numbers for each control point. The predicted value of the scan line and element is compared with the value measured when the control points were identified by scan line and element in the Landsat data. The rms (i.e., the square root of the average of the squares of the differences between the measured and predicted value) is computed. This value is used to determine the expected geometric accuracy of the application and is used as a guide to possible errors in the selection of control points. Control points that indicate large differences between measured and predicted values should be examined for the cause of such differences.

Finally, the program writes to disk information, which is read and used by the GEOREF module to set up the mapping formulas. If the mapping formulas in the GEOREF module were changed to some other map projection, the CONSTANTS module would also have to be changed to reflect such modification.

The GEOREF module (appendix B, fig. B-3) requires 67 135 octal (28 253 decimal) words (16 bit) of storage. The GEOREF module accepts Landsat-data-derived information as stored on a PSUTAP and the mapping coefficients computed by the CONSTANTS module. Initial easting and northing values that define the boundaries of the GEOREF scene and the number of input tapes to be used to build the GEOREF scene are inputs to the GEOREF module.

The disk storage should be considered in terms of a square grid oriented north-south and east-west. Based on the mapping formulas currently compiled in the module, the grid size is 50 meters.

The area representd by each GEOREF scene is somewhat larger than 1° by 1°; that is, 115 000 meters north-south by 100 000 meters east-west. The GEOREF module operates on the assumption that this region is represented on disk storage. If the disk storage has not been previously used for GEOREF, the GEOREF module must be instructed to initialize the disk storage by placing a no-operation code (-1) in each location. Operation of the GEOREF module then is based on the rectangular region defined by scan lines and elements in the Landsat coordinate system, which is to be used to update the data stored on disk. The inverses of equations (1) and (2) are used to determine the region in the disk storage, which is to be updated. The information stored on the disk for the region to be updated is read into core memory. Equations (1) and (2) are then used to compute the Landsat scan line and element of each grid cell in the region to be updated. Using the Landsat data at the nearest scan line and element to the one computed, the grid cell is updated. This process continues to completion, and the updated information is placed back on disk in the appropriate location; the result is Landsat-data-derived information stored in a rectangular array that corresponds to a 50-meter UTM grid. Finally, the geographically referenced data on disk are written to a tape using the format of PSUTAP (appendix A).

The FILE COPY (appendix B, fig. B-4) requires 47 451 octal (20 265 decimal) words (16 bit) of storage. The module can be used to embed a rectangular array of cross-shaped tick marks in the geographically referenced data. These tick marks can be defined as a UTM grid or can be used for registration if the PSUTAP so generated is to be used to drive a plotting device.

CONCLUDING REMARKS

A procedure has been described for mapping Landsat surface cover identification data with the universal transverse Mercator grid system. In the procedure, a series of computer modules is used to make approximations of universal transverse Mercator locations for all picture elements from the grid locations of several control points, and other modules provide storage and display of the data. Application of the procedure produces geographically referenced data maps that can be updated. Modification of the procedure would enable the correlation of other Landsat data with universal transverse Mercator coordinates.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, July 25, 1977
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2. Thomas, Valerie L.: Generation and Physical Characteristics of the ERTS MSS System Corrected Computer Compatible Tapes. NASA TM X-70426, 1973.

3. Whitley, Sidney L.: Low-Cost Data Analysis Systems for Processing Multispectral Scanner Data. NASA TR R-467, 1976.

TABLE I.- CONTROL POINTS CHOSEN FROM ONE LANDSAT SCENE

Point count	Easting	Northing	Scan	Element
1	625142.	3432046.	296.	379.
2	609030.	3438294.	252.	78.
3	610645.	3429004.	363.	142.
4	622086.	3423561.	406.	358.
5	628058.	3412487.	531.	504.
6	620741.	3399777.	703.	430.
7	606157.	3398673.	749.	184.
8	607447.	3387918.	878.	250.
9	612155.	3381867.	943.	354.
10	600959.	3379677.	994.	171.
11	609395.	3369109.	1107.	358.
12	582804.	3329272.	1658.	63.
13	761443.	3370516.	768.	2926.
14	598151.	3313588.	1820.	389.
15	602327.	3305380.	1913.	492.
16	583955.	3299024.	2031.	205.
17	580154.	3293942.	2103.	158.
18	597819.	3300552.	1982.	435.
19	578515.	3284613.	2221.	170.
20	638712.	3447414.	77.	548.
21	636825.	3438466.	191.	550.
22	633394.	3425516.	359.	543.
23	632922.	3420639.	421.	554.
24	636216.	3411702.	523.	645.
25	628300.	3395439.	741.	575.
26	627349.	3368943.	1071.	664.
27	626551.	3350323.	1304.	724.
28	612106.	3301511.	1940.	675.
29	636353.	3380953.	904.	770.
30	630699.	3359820.	1178.	756.
31	653236.	3404086.	581.	963.
32	644815.	3380854.	886.	912.
33	646559.	3363494.	1099.	1010.
34	761679.	3362348.	868.	2963.
35	632811.	3349723.	1298.	833.
36	633009.	3341895.	1395.	867.
37	631090.	3329804.	1549.	883.
38	754288.	3294671.	1722.	3109.
39	621808.	3293027.	2025.	871.
40	631646.	3292844.	2005.	1038.

TABLE I.- Continued

Point count	Easting	Northing	Scan	Element
41	662366.	3392578.	705.	1162.
42	659760.	3376142.	913.	1183.
43	661054.	3364266.	1057.	1250.
44	654024.	3346423.	1294.	1204.
45	649789.	3334460.	1451.	1179.
46	646710.	3329255.	1523.	1149.
47	649349.	3325821.	1559.	1206.
48	642446.	3307326.	1803.	1164.
49	641399.	3300215.	1894.	1174.
50	634461.	3292255.	2007.	1088.
51	637086.	3279266.	2162.	1183.
52	679461.	3412962.	415.	1371.
53	681569.	3392016.	671.	1487.
54	677576.	3379017.	840.	1471.
55	750688.	3287859.	1815.	3075.
56	662021.	3352336.	1204.	1315.
57	665665.	3335314.	1407.	1444.
58	658365.	3344703.	1306.	1283.
59	662818.	3329841.	1482.	1417.
60	654540.	3280881.	2106.	1472.
61	652217.	3272860.	2209.	1463.
62	653771.	3267615.	2271.	1510.
63	688979.	3396212.	603.	1596.
64	689003.	3394204.	627.	1604.
65	704910.	3422337.	248.	1762.
66	745773.	3272229.	2019.	3054.
67	699007.	3399414.	542.	1753.
68	691839.	3393862.	626.	1653.
69	702672.	3385662.	705.	1868.
70	693010.	3371790.	897.	1759.
71	684859.	3367156.	972.	1641.
72	690202.	3351637.	1153.	1792.
73	677677.	3313454.	1652.	1734.
74	678191.	3299763.	1822.	1795.
75	671621.	3293867.	1908.	1706.
76	671167.	3285584.	2012.	1733.
77	669843.	3267292.	2241.	1783.
78	719885.	3407829.	395.	2071.
79	776891.	3370261.	738.	3193.
80	708764.	3355838.	1061.	2088.

TABLE I.- Continued

Point count	Easting	Northing	Scan	Element
81	704285.	3358588.	1036.	2002.
82	704865.	3350391.	1137.	2044.
83	698207.	3311430.	1634.	2086.
84	683485.	3300417.	1802.	1881.
85	683460.	3290862.	1921.	1920.
86	685651.	3268610.	2191.	2044.
87	685416.	3261419.	2281.	2069.
88	727170.	3412392.	323.	2177.
89	760485.	3295954.	1694.	3211.
90	717678.	3365692.	920.	2200.
91	717606.	3351354.	1098.	2255.
92	717694.	3345824.	1167.	2281.
93	719687.	3341710.	1212.	2326.
94	710188.	3339066.	1266.	2179.
95	704084.	3291822.	1864.	2263.
96	704287.	3288847.	1901.	2278.
97	698344.	3272989.	2111.	2241.
98	701644.	3271477.	2122.	2304.
99	731252.	3384765.	656.	2355.
100	723695.	3376731.	771.	2257.
101	726700.	3346646.	1137.	2428.
102	705462.	3269454.	2139.	2376.
103	707414.	3268950.	2142.	2411.
104	752238.	3411809.	279.	2606.
105	752375.	3404056.	373.	2637.
106	741377.	3385165.	631.	2526.
107	747649.	3379396.	688.	2654.
108	749336.	3384591.	620.	2663.
109	739810.	3364430.	889.	2581.
110	734632.	3353963.	1030.	2534.
111	736060.	3339871.	1201.	2615.
112	755647.	3288487.	1796.	3157.
113	729111.	3315200.	1522.	2594.
114	730687.	3308904.	1597.	2648.
115	724626.	3278344.	1988.	2667.
116	713850.	3272029.	2089.	2508.
117	710304.	3255631.	2299.	2514.
118	715120.	3255504.	2291.	2595.
119	754275.	3294626.	1723.	3110.
120	770369.	3413147.	223.	2910.

TABLE I.- Concluded

Point count	Easting	Northing	Scan	Element
121	753241.	3377734.	696.	2756.
122	258220.	3370705.	772.	2870.
123	754861.	3356567.	954.	2869.
124	747806.	3344262.	1122.	2797.
125	742796.	3305348.	1615.	2869.
126	742985.	3297431.	1713.	2904.
127	730528.	3300442.	1702.	2679.
128	729936.	3288164.	1855.	2718.
129	731659.	3281996.	1928.	2772.
130	726659.	3272954.	2051.	2723.
131	737756.	3272568.	2032.	2914.
132	726526.	3258179.	2234.	2780.
133	730910.	3258989.	2213.	2852.

TABLE II.- RESIDUAL ERRORS OF MAPPED CONTROL POINTS FROM TABLE I

AFTER SKEW AND TANGENT EFFECTS WERE CORRECTED

[Tangent and skew corrections applied.
A1 = 0.4413666E 05 A2 = -0.2120436E-02 A3 = -0.1238801E-01
B1 = -0.7644260E 04 B2 = 0.1742026E-01 B3 = -0.8570599E-03]

Point count	Scan	Residual	Element	Residual
1	294.87	-0.1128E 01	304.41	-0.3336E 01
2	251.64	-.3642E 00	18.38	.8846E 00
3	363.30	.2959E 00	54.47	.1630E 01
4	406.46	.4640E 00	258.44	-.1244E 01
5	530.99	-.1440E-01	371.97	-.2025E 01
6	703.95	.9524E 00	255.40	-.1466E 01
7	748.55	-.4470E 00	2.29	.3240E 01
8	879.05	.1051E 01	33.98	.1649E 01
9	944.03	.1028E 01	121.18	.5009E 00
10	994.90	.8977E 00	-71.98	.3031E 01
11	1107.93	.9263E 00	84.03	.3441E 00
12	1657.81	-.1885E 00	-345.05	.5548E 01
13	768.09	.8813E-01	2731.54	-.2900E 01
14	1819.56	-.4370E 00	-64.26	-.1026E 01
15	1912.39	-.6113E 00	15.53	-.1451E 01
16	2030.08	-.9165E 00	-299.07	.1786E 01
17	2101.10	-.1900E 01	-360.93	.5145E 01
18	1981.76	-.2432E 00	-58.87	-.7413E 00
19	2220.14	-.8574E 00	-381.49	.2531E 01
20	75.72	-.1282E 01	527.63	-.4419E 01
21	190.57	-.4324E 00	502.43	-.3624E 01
22	358.27	-.7325E 00	453.76	-.3287E 01
23	419.68	-.1315E 01	449.71	-.1341E 01
24	523.41	.4116E 00	514.76	-.2357E 01
25	741.66	.6631E 00	390.80	-.2279E 01
26	1071.91	.9121E 00	396.94	-.2180E 01
27	1304.27	.2690E 00	399.00	-.2119E 01
28	1932.58	-.4180E 00	189.19	-.3925E 01
29	904.04	.3979E-01	543.50	-.3596E 01
30	1177.82	-.1753E 00	463.12	-.9861E 00
31	581.67	.6687E 00	817.78	-.3088E 01
32	887.32	.1323E 01	690.99	-.2954E 01
33	1098.68	-.3188E 00	736.25	-.1527E 01
34	868.77	.7732E 00	2742.65	-.2916E 01
35	1298.43	.4277E 00	508.56	-.2483E 01
36	1394.98	-.1855E-01	518.72	-.2287E 01

TABLE II.- Continued

Point count	Scan	Residual	Element	Residual
37	1548.83	-0.1660E 00	495.65	-0.2334E 01
38	1722.83	.8286E 00	2671.90	-.7309E 01
39	2024.11	-.8906E 00	365.48	-.2524E 01
40	2005.52	.5156E 00	537.01	-.1707E 01
41	704.87	-.1296E 00	986.69	-.1744E 01
42	914.01	.1006E 01	955.38	-.9995E 00
43	1058.38	.1382E 01	988.10	.9060E 00
44	1294.33	.3276E 00	880.92	-.2395E 01
45	1451.51	.5054E 00	817.40	-.1983E 01
46	1522.51	-.4863E 00	768.23	-.3237E 01
47	1559.46	.4585E 00	817.14	-.2172E 01
48	1803.21	.2119E 00	712.74	-.2684E 01
49	1893.52	-.4771E 00	700.60	-.2802E 01
50	2006.84	-.1567E 00	586.56	-.2054E 01
51	2162.18	.1846E 00	643.42	-.9580E 00
52	416.10	.1104E 01	1267.02	-.1809E 01
53	671.11	.1138E 00	1321.69	.2417E 00
54	840.61	.6123E 00	1263.27	-.2295E 00
55	1814.85	-.1509E 00	2615.03	-.6012E 01
56	1204.12	.1201E 00	1015.17	-.8318E 00
57	1407.26	.2622E 00	1093.24	-.3550E 00
58	1306.43	.4302E 00	958.02	-.1074E 01
59	1481.10	-.9014E 00	1048.33	-.3477E 00
60	2105.17	-.8320E 00	946.09	-.1411E 01
61	2209.46	.4580E 00	912.49	.9663E 00
62	2271.14	.1377E 00	944.06	.6890E 00
63	603.42	.4211E 00	1447.18	.1097E 01
64	628.25	.1246E 01	1449.32	.1263E 01
65	246.00	-.1996E 01	1702.31	.1788E 01
66	2018.90	-.1045E 00	2542.81	-.6137E 01
67	542.49	.4912E 00	1619.12	.1572E 01
68	626.47	.4685E 00	1499.01	.2126E 01
69	705.08	.7959E-01	1694.76	.2578E 01
70	897.41	.4138E 00	1538.33	.2798E 01
71	972.10	.1035E 00	1400.31	.3804E 00
72	1153.02	.2344E-01	1506.69	.3264E 01
73	1652.59	.5933E 00	1321.22	-.3921E 00
74	1821.11	-.8926E 00	1341.91	.1498E 01
75	1908.08	.7861E-01	1232.51	.1804E 01
76	2011.65	-.3491E 00	1231.70	.1085E 01

TABLE II.- Continued

Point count	Scan	Residual	Element	Residual
77	2241.06	0.5957E-01	1224.32	0.8638E 00
78	393.98	-.1024E 01	1975.61	.3025E 01
79	738.49	.4907E 00	3000.87	-.8823E 01
80	1061.62	.6221E 00	1826.44	.3897E 01
81	1037.05	.1052E 01	1746.06	.3284E 01
82	1137.37	.3667E 00	1763.19	.3529E 01
83	1634.13	.1338E 00	1680.60	.4047E 01
84	1801.78	-.2197E 00	1433.57	.3437E 01
85	1920.20	-.7993E 00	1441.33	.2311E 01
86	2191.21	.2129E 00	1498.57	.2907E 01
87	2280.79	-.2070E 00	1500.64	.3043E 01
88	322.00	-.9983E 00	2098.61	.2276E 01
89	1693.79	-.2056E 00	2778.76	-.9049E 01
90	920.65	.6489E 00	1973.28	.3997E 01
91	1098.42	.4209E 00	1984.31	.4140E 01
92	1166.74	-.2603E 00	1990.59	.2458E 01
93	1213.48	.1478E 01	2028.83	.5774E 01
94	1266.37	.3740E 00	1865.62	.3294E 01
95	1864.58	.5762E 00	1799.78	.3620E 01
96	1901.00	.0000E 01	1805.87	.3732E 01
97	2110.05	-.9492E 00	1715.93	.2728E 01
98	2121.78	-.2158E 00	1774.71	.1621E 01
99	655.59	-.4104E 00	2193.40	.3379E 01
100	771.14	.1389E 00	2068.64	.5466E 01
101	1137.46	.4604E 00	2146.77	.3831E 01
102	2138.75	-.2510E 00	1842.96	.2965E 01
103	2140.85	-.1146E 01	1877.39	.2439E 01
104	276.07	-.1931E 01	2535.80	.9092E 00
105	371.82	-.1177E 01	2544.83	.2926E 01
106	629.17	-.1835E 01	2369.43	.2549E 01
107	687.33	-.6680E 00	2483.64	.2721E 01
108	619.40	-.6008E 00	2508.57	.1649E 01
109	889.35	.3530E 00	2359.91	.3023E 01
110	1030.00	-.1953E-02	2278.67	.2793E 01
111	1201.54	.5420E 00	2315.63	.2735E 01
112	1796.55	.5542E 00	2700.88	-.7598E 01
113	1521.90	-.9863E-01	2215.72	.2834E 01
114	1596.55	-.4458E 00	2248.57	.1658E 01
115	1987.98	-.1611E-01	2169.18	.2510E 00
116	2089.06	.6348E-01	1986.87	.2981E 01

TABLE II.- Concluded

Point count	Scan	Residual	Element	Residual
117	2299.72	0.7217E 00	1939.15	0.1265E 01
118	2291.08	.8301E-01	2023.16	.1271E 01
119	1723.41	.4136E 00	2671.72	-.7501E 01
120	221.05	-.1952E 01	2850.50	-.2895E 01
121	696.06	.6348E-01	2582.48	.4395E 00
122	772.58	.5811E 00	2675.24	-.1043E 01
123	954.85	.8452E 00	2628.84	-.1438E 01
124	1122.24	.2393E 00	2516.48	.3750E 00
125	1614.93	-.7031E-01	2462.56	-.1716E 01
126	1712.60	-.3950E 00	2472.64	-.2737E 01
127	1701.72	-.2813E 00	2253.05	.1152E 00
128	1855.07	.7422E-01	2253.26	.2832E 00
129	1927.83	-.1704E 00	2288.56	-.4980E 00
130	2050.44	-.5557E 00	2209.21	-.7744E 01
131	2031.70	-.3042E 00	2402.86	-.2549E 01
132	2233.76	-.2412E 00	2219.56	-.5176E 00
133	2214.43	.1429E 01	2295.24	-.2997E 01

Line error= .71479 Element error= 2.98741
RMS error= 181 meters

TABLE III.- RESIDUAL ERRORS OF MAPPED CONTROL POINTS FROM TABLE I

AFTER SKEW, TANGENT, AND MIRROR VELOCITY EFFECTS WERE CORRECTED

[Tangent correction applied; input amplitude of mirror correction curve = 360; input period = 6.7; input phase shift = 0.45; and mirror and skew corrections applied.
A1 = 0.4413666E 05 A2 = -0.2120436E-02 A3 = -0.1238801E-01
B1 = -0.7635372E 04 B2 = 0.1749382E-01 B3 = -0.8745641E-03]

Point count	Scan	Residual	Element	Residual
1	294.87	-0.1128E 01	299.20	-0.2881E 01
2	251.64	-.3642E 00	11.88	-.2241E 01
3	363.30	.2959E 00	48.26	-.6146E 00
4	406.46	.4640E 00	253.16	-.9761E 00
5	530.99	-.1440E-01	367.32	-.5323E 00
6	703.95	.9524E 00	250.43	-.5363E 00
7	748.55	-.4470E 00	-3.73	.1559E 01
8	879.05	.1051E 01	28.24	.7704E 00
9	944.03	.1028E 01	115.90	.7461E 00
10	994.90	.8977E 00	-78.05	.1191E 01
11	1107.93	.9263E 00	78.77	.6316E 00
12	1657.81	-.1885E 00	-351.57	.2255E 01
13	768.09	.9813E-01	2737.44	-.2598E 00
14	1819.56	-.4370E 00	-69.37	-.4337E 00
15	1912.39	-.6113E 00	10.86	-.8698E-02
16	2030.08	-.9165E 00	-304.98	.3888E 00
17	2101.10	-.1900E 01	-367.03	.3163E 01
18	1981.76	-.2432E 00	-63.78	.2589E 00
19	2220.14	-.8574E 00	-387.54	.6952E 00
20	75.72	-.1282E 01	523.15	-.2659E 01
21	190.57	-.4324E 00	497.97	-.1843E 01
22	358.27	-.7325E 00	449.27	-.1544E 01
23	419.68	-.1315E 01	445.28	.4716E 00
24	523.41	.4116E 00	510.72	-.8923E-01
25	741.66	.6631E 00	386.46	-.3368E 00
26	1071.91	.9121E 00	393.00	.1746E 00
27	1304.27	.2690E 00	395.32	.4227E 00
28	1939.58	-.4180E 00	185.32	-.1520E 01
29	904.04	.3979E-01	540.01	-.9819E 00
30	1177.82	-.1753E 00	459.58	.1621E 01
31	581.67	.6687E 00	815.13	-.5544E 00
32	887.32	.1323E 01	688.13	-.3232E 00
33	1098.68	-.3188E 00	733.82	.9014E 00

TABLE III.- Continued

Point count	Scan	Residual	Element	Residual
34	868.77	0.7732E 00	2748.71	0.2578E 00
35	1298.43	.4277E 00	505.36	.1962E 00
36	1394.98	-.1855E-01	515.67	.3916E 00
37	1548.83	-.1660E 00	492.67	.3361E 00
38	1722.83	.8286E 00	2678.60	-.1914E 01
39	2024.11	-.8906E 00	362.46	.1669E 00
40	2005.52	.5156E 00	534.72	.6501E 00
41	704.87	-.1296E 00	984.91	.5933E-01
42	914.01	.1006E 01	953.70	.6997E 00
43	1058.38	.1382E 01	986.72	.2238E 01
44	1294.33	.3276E 00	879.34	-.8022E 00
45	1451.51	.5054E 00	815.72	-.2495E 00
46	1522.51	-.4863E 00	766.41	-.1356E 01
47	1559.46	.4585E 00	815.58	-.5825E 00
48	1803.21	.2119E 00	710.99	-.8728E 00
49	1893.52	-.4771E 00	698.90	-.1039E 01
50	2006.84	-.1567E 00	584.48	.1150E 00
51	2162.18	.1846E 00	641.77	.7690E 00
52	416.10	.1104E 01	1266.14	-.1280E 01
53	671.11	.1138E 00	1321.34	-.2051E-01
54	840.61	.6123E 00	1262.85	-.3755E 00
55	1814.85	-.1509E 00	2621.58	-.1145E 01
56	1204.12	.1201E 00	1014.07	.9180E-01
57	1407.26	.2622E 00	1092.70	-.3042E 00
58	1306.43	.4302E 00	956.79	.5713E-01
59	1481.10	-.9014E 00	1047.69	-.1045E 00
60	2105.17	-.8320E 00	945.69	-.1545E 01
61	2209.46	.4580E 00	912.07	.9048E 00
62	2271.14	.1377E 00	943.84	.2966E 00
63	603.42	.4211E 00	1447.30	.6689E-01
64	628.25	.1246E 01	1449.47	.1797E 00
65	246.00	-.1996E 01	1703.14	-.3135E 00
66	2018.90	-.1045E 00	2549.27	-.1590E 01
67	542.49	.4912E 00	1619.92	-.4702E 00
68	626.47	.4685E 00	1499.38	.7144E 00
69	705.08	.7959E-01	1696.07	-.5762E-01
70	897.41	.4138E 00	1539.17	.7373E 00
71	972.10	.1035E 00	1400.63	-.9448E 00
72	1153.02	.2344E-01	1507.67	.1019E 01
73	1652.59	.5933E 00	1321.96	-.2303E 01

TABLE III.- Continued

Point count	Scan	Residual	Element	Residual
74	1821.11	-0.8926E 00	1342.92	-0.7515E 00
75	1908.08	.7861E-01	1233.15	.8398E-01
76	2011.65	-.3491E 00	1232.45	-.8071E 00
77	2241.06	.5957E-01	1225.28	-.1313E 01
78	393.98	-.1024E 01	1977.80	-.2378E 00
79	738.49	.4907E 00	3007.91	-.2131E 01
80	1061.62	.6221E 00	1828.72	.6318E 00
81	1037.05	.1052E 01	1747.96	.1733E 00
82	1137.37	.3667E 00	1765.28	.3281E 00
83	1634.13	.1338E 00	1682.88	.7925E 00
84	1801.78	-.2197E 00	1434.96	.7671E 00
85	1920.20	-.7993E 00	1442.88	-.5244E 00
86	2191.21	.2129E 00	1500.67	-.2754E 00
87	2280.79	-.2070E 00	1502.85	-.1812E 00
88	322.00	-.9983E 00	2101.25	-.1036E 01
89	1693.79	-.2056E 00	2785.89	-.2055E 01
90	920.65	.6489E 00	1976.04	.7231E 00
91	1098.42	.4209E 00	1987.32	.9604E 00
92	1166.74	-.2603E 00	1993.70	-.6685E 00
93	1213.48	.1478E 01	2032.16	.2813E 01
94	1266.37	.3740E 00	1868.30	.9277E-02
95	1864.58	.5762E 00	1802.84	.4707E 00
96	1901.00	.0000E 01	1808.99	.6221E 00
97	2110.05	-.9492E 00	1718.89	-.4644E 00
98	2121.78	-.2158E 00	1777.94	-.1417E 01
99	655.59	-.4104E 00	2196.82	.5020E 00
100	771.14	.1389E 00	2071.65	.2285E 01
101	1137.46	.4604E 00	2150.53	.1333E 01
102	2138.75	-.2510E 00	1846.50	.2114E 00
103	2140.85	-.1146E 01	1881.09	-.1387E 00
104	276.07	-.1931E 01	2540.30	-.2832E 00
105	371.82	-.1177E 01	2549.47	.2040E 01
106	629.17	-.1835E 01	2373.60	.6914E 00
107	687.33	-.6680E 00	2488.37	.2017E 01
108	619.40	-.6008E 00	2513.33	.1030E 01
109	889.35	.3530E 00	2364.32	.1629E 01
110	1030.00	-.1953E-02	2282.89	.1013E 01
111	1201.54	.5420E 00	2320.20	.1658E 01
112	1796.55	.5542E 00	2707.79	-.1450E 01
113	1521.90	-.9863E-01	2220.21	.1574E 01

TABLE III.- Concluded

Point count	Scan	Residual	Element	Residual
114	1596.55	-0.4458E 00	2253.28	0.9053E 00
115	1987.98	-.1611E-01	2173.98	-.2998E 00
116	2089.06	.6348E-01	1990.99	.1021E 01
117	2299.72	.7217E 00	1943.30	-.6514E 00
118	2291.08	.8301E-01	2027.66	.3027E-01
119	1723.41	.4136E 00	2678.42	-.2096E 01
120	221.05	-.1952E 01	2856.31	-.4990E 00
121	696.06	.6348E-01	2587.64	.8604E 00
122	772.58	.5811E 00	2680.89	.8242E 00
123	954.85	.8452E 00	2634.50	.4199E 00
124	1122.24	.2393E 00	2521.84	.1304E 01
125	1614.93	-.7031E-01	2468.23	.1514E 00
126	1712.60	-.3950E 00	2478.46	-.3887E 00
127	1701.72	-.2813E 00	2257.90	-.3154E 00
128	1855.07	.7422E-01	2258.29	.2813E 00
129	1927.83	-.1704E 00	2293.82	.1338E 00
130	2050.44	-.5557E 00	2214.26	-.7158E 00
131	2031.70	-.3042E 00	2408.73	-.5273E-01
132	2233.76	-.2412E 00	2224.85	.2158E 00
133	2214.43	.1429E 01	2300.84	-.1346E 01

Line error= .71479 Element error= 1.09350
RMS error= 86 m

TABLE IV.- CONTROL POINTS CHOSEN FROM A 1:250 000-SCALE MAP

Point count	Easting	Northing	Scan	Element
1	606144.	3398624.	749.	184.
2	607363.	3388107.	878.	250.
3	727139.	3412387.	323.	2177.
4	723726.	3376723.	771.	2257.
5	752402.	3404049.	373.	2637.
6	753175.	3377922.	696.	2756.
7	752210.	3411731.	278.	2606.
8	770347.	3413047.	223.	2910.
9	612074.	3381967.	943.	354.
10	628212.	3412354.	531.	504.
11	601010.	3379685.	994.	171.
12	632928.	3420535.	421.	554.
13	636289.	3411782.	523.	645.
14	626728.	3350264.	1304.	724.
15	636411.	3380808.	904.	770.
16	644843.	3380951.	886.	912.
17	704865.	3350466.	1137.	2044.
18	632830.	3349780.	1298.	833.
19	662285.	3392634.	705.	1162.
20	659669.	3376326.	913.	1183.
21	653170.	3404051.	581.	963.
22	681569.	3392051.	671.	1487.
23	693008.	3371732.	897.	1759.

A1 = 0.4413077E 05 A2 = -0.2111947E-02 A3 = -0.1238790E-01
B1 = -0.7687845E 04 B2 = 0.1749737E-01 B3 = -0.8598931E-03

Point Count	Scan	Residual	Element	Residual
1	748.80	-0.1995E 00	-4.38	-0.9131E 00
2	876.51	-.1490E 01	26.00	-.1476E 01
3	322.77	-.2292E 00	2100.88	-.1404E 01
4	771.78	.7810E 00	2071.83	.2469E 01
5	372.71	-.2931E 00	2550.09	.2655E 01
6	694.73	-.1267E 01	2586.08	-.7021E 00
7	277.95	-.5139E-01	2540.12	-.4561E 00
8	223.34	.3417E 00	2856.34	-.4639E 00
9	942.62	-.3782E 00	113.71	-.1443E 01
10	532.11	.1108E 01	369.95	.2096E 01
11	994.26	.2578E 00	-77.92	.1318E 01

TABLE IV.- Concluded

Point count	Scan	Residual	Element	Residual
12	420.80	-0.1973E 00	445.43	0.6224E 00
13	522.14	-.8643E 00	511.77	.9562E 00
14	1304.41	.4072E 00	397.37	.2473E 01
15	905.58	.1581E 01	540.54	-.4563E 00
16	886.00	.1709E-02	687.95	-.5017E 00
17	1136.88	-.1167E 00	1764.39	-.5552E 00
18	1297.52	-.4844E 00	504.56	-.6049E 00
19	704.44	-.5627E 00	983.09	-.1757E 01
20	911.98	-.1016E 01	951.34	-.1652E 01
21	582.25	.1255E 01	813.79	-.1894E 01
22	670.93	-.6738E-01	1321.02	-.3418E 00
23	898.48	.1484E 01	1538.64	.2051E 00

Line error= .80761 Element error= 1.40451
RMS error= 105 m

TABLE V.- CONTROL POINTS CHOSEN FROM 1:24 000 AND 1:62 500-SCALE MAPS

Point count	Easting	Northing	Scan	Element
1	606157.	3398673.	749.	184.
2	607447.	3387918.	878.	250.
3	727170.	3412392.	323.	2177.
4	723695.	3376731.	771.	2257.
5	752375.	3404056.	373.	2637.
6	753241.	3377734.	696.	2756.
7	752238.	3411809.	278.	2606.
8	770369.	3413147.	223.	2910.
9	612155.	3381867.	943.	354.
10	628058.	3412487.	531.	504.
11	600959.	3379677.	994.	171.
12	632922.	3420639.	421.	554.
13	636216.	3411702.	523.	645.
14	626551.	3350323.	1304.	724.
15	636353.	3380953.	904.	770.
16	644815.	3380854.	886.	912.
17	704865.	3350391.	1137.	2044.
18	632811.	3349723.	1298.	833.
19	662366.	3392578.	705.	1162.
20	659760.	3376142.	913.	1183.
21	653236.	3404086.	581.	963.
22	681569.	3392016.	671.	1487.
23	693010.	3371790.	897.	1759.

A1 = 0.4405840E 05 A2 = -0.2111437E-02 A3 = -0.1236669E-01
B1 = -0.7672661E 04 B2 = 0.1749280E-01 B3 = -0.8634630E-03

Point count	Scan	Residual	Element	Residual
1	748.19	-0.8130E 00	-3.90	0.1385E 01
2	878.47	.4670E 00	27.95	.4758E 00
3	323.02	.1685E-01	2101.11	-.1181E 01
4	771.36	.3628E 00	2071.11	.1749E 01
5	372.89	-.1132E 00	2549.21	.1778E 01
6	696.57	.5745E 00	2587.09	.3057E 00
7	277.30	-.7029E 00	2540.12	-.4590E 00
8	222.47	-.5320E 00	2856.13	-.6787E 00
9	943.36	.3572E 00	115.53	.3795E 00
10	531.11	.1108E 00	367.28	-.5751E 00
11	994.08	.7983E-01	-78.43	.8112E 00

TABLE V.- Concluded

Point count	Scan	Residual	Element	Residual
12	420.03	-0.9725E 00	445.32	0.5145E 00
13	523.59	.5935E 00	510.66	-.1489E 00
14	1303.06	-.9438E 00	394.59	-.3085E 00
15	903.57	-.4321E 00	539.61	-.1383E 01
16	886.93	.9250E 00	687.72	-.7341E 00
17	1136.86	-.1401E 00	1764.47	-.4814E 00
18	1297.26	-.7417E 00	504.62	-.5481E 00
19	704.88	-.1199E 00	984.61	-.2390E 00
20	913.64	.6416E 00	953.22	.2214E 00
21	581.84	.8416E 00	814.97	-.7158E 00
22	671.28	.2842E 00	1321.01	-.3447E 00
23	897.26	.2561E 00	1538.61	.1772E 00

Line error= .56564 Element error= .82868
RMS error= 66 m

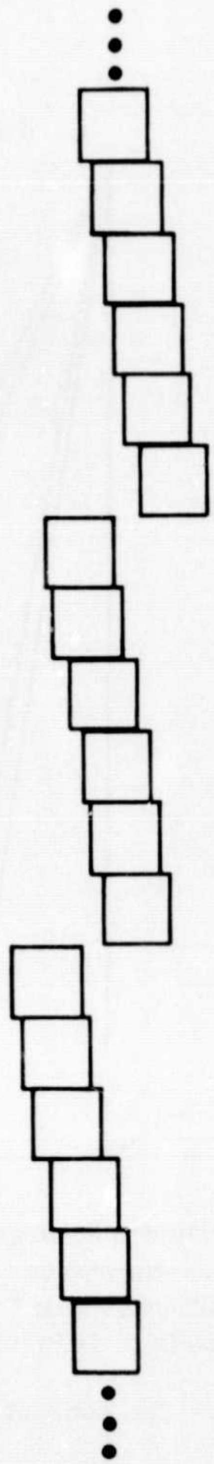


Figure 1.- The skew effect: a column of elements from a Landsat scene oriented to show their relative locations with respect to a UTM grid.

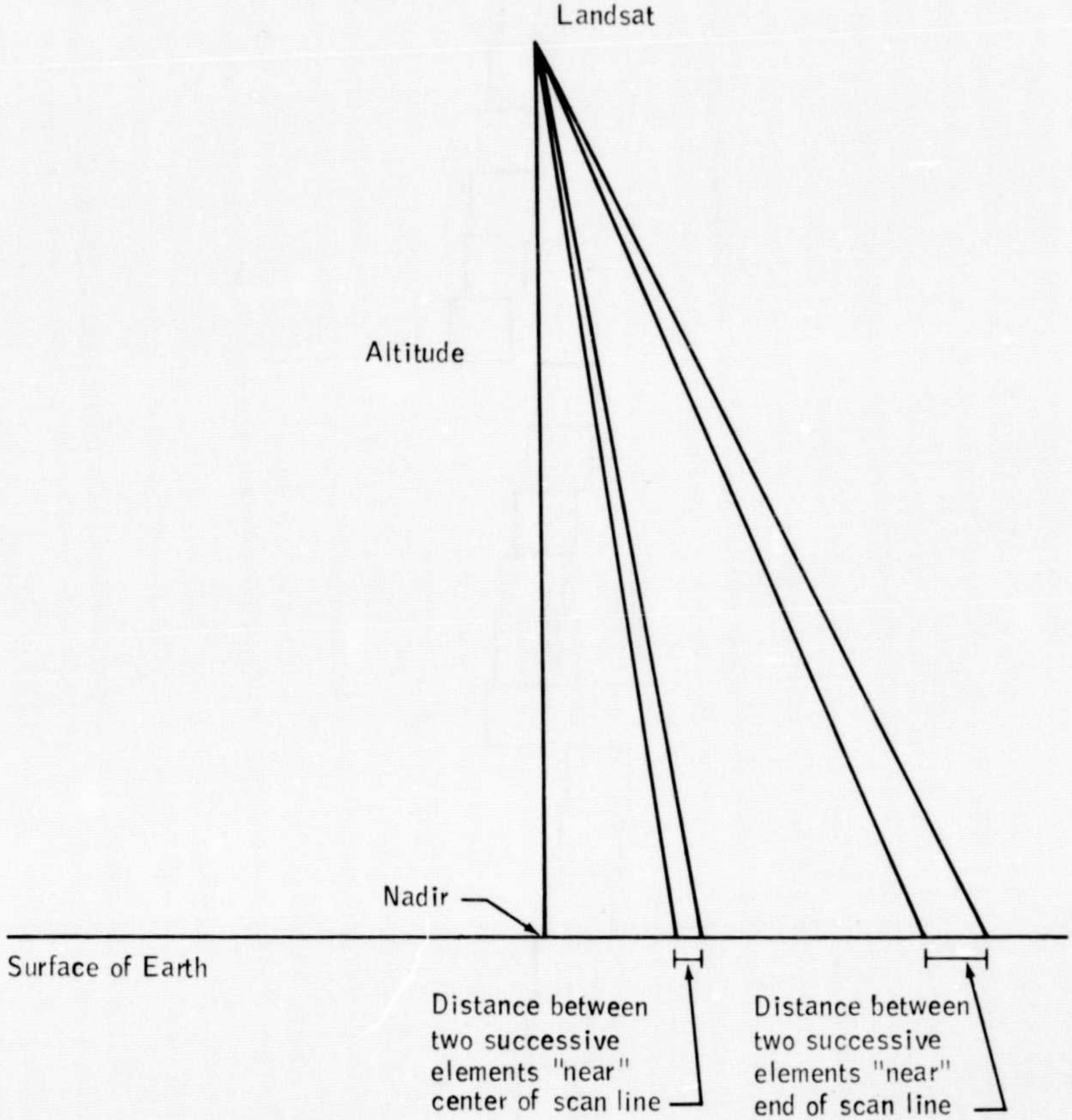
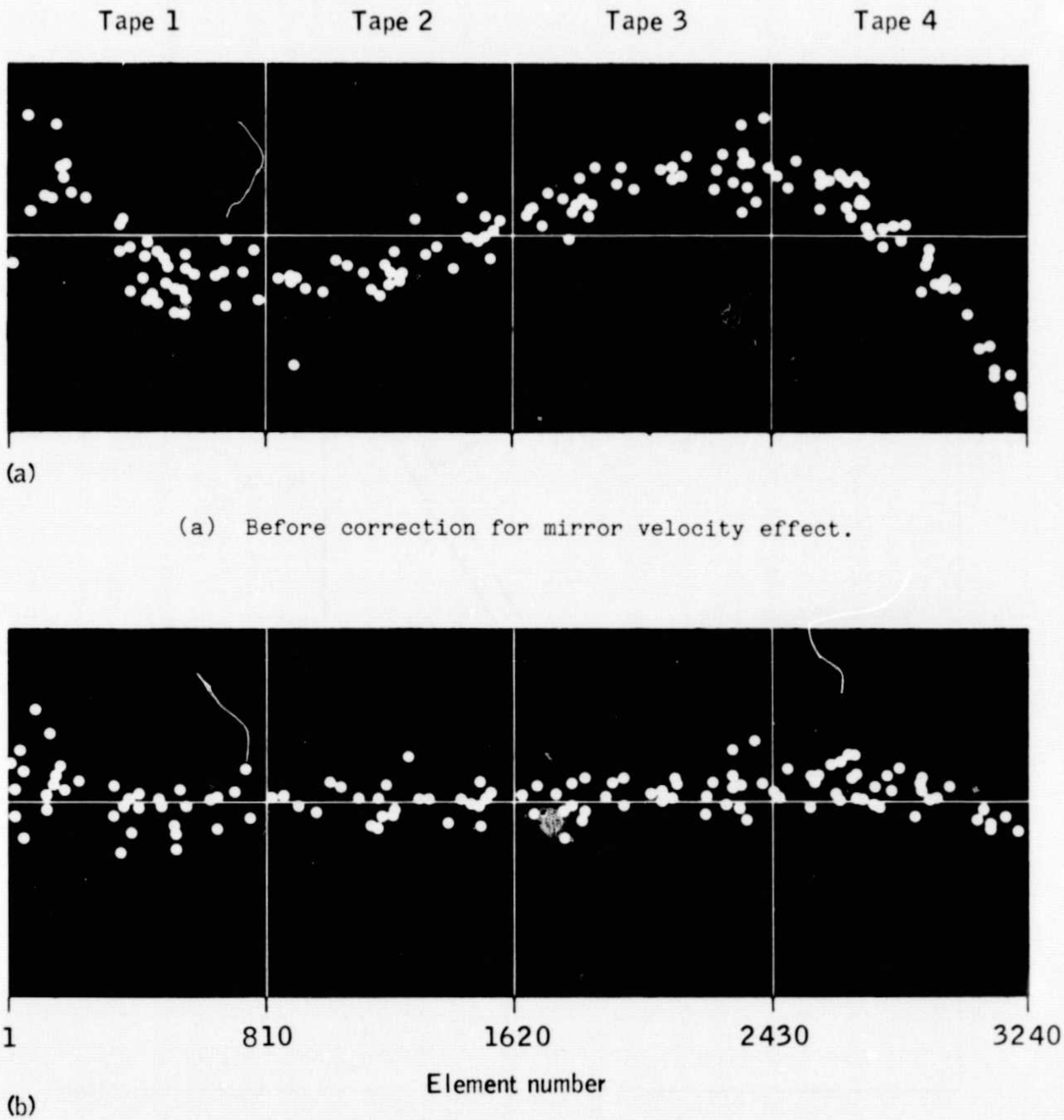


Figure 2.- The tangent effect.



(a) Before correction for mirror velocity effect.

(b) After correction for mirror velocity effect.

Figure 3.- Residual errors of mapped points.

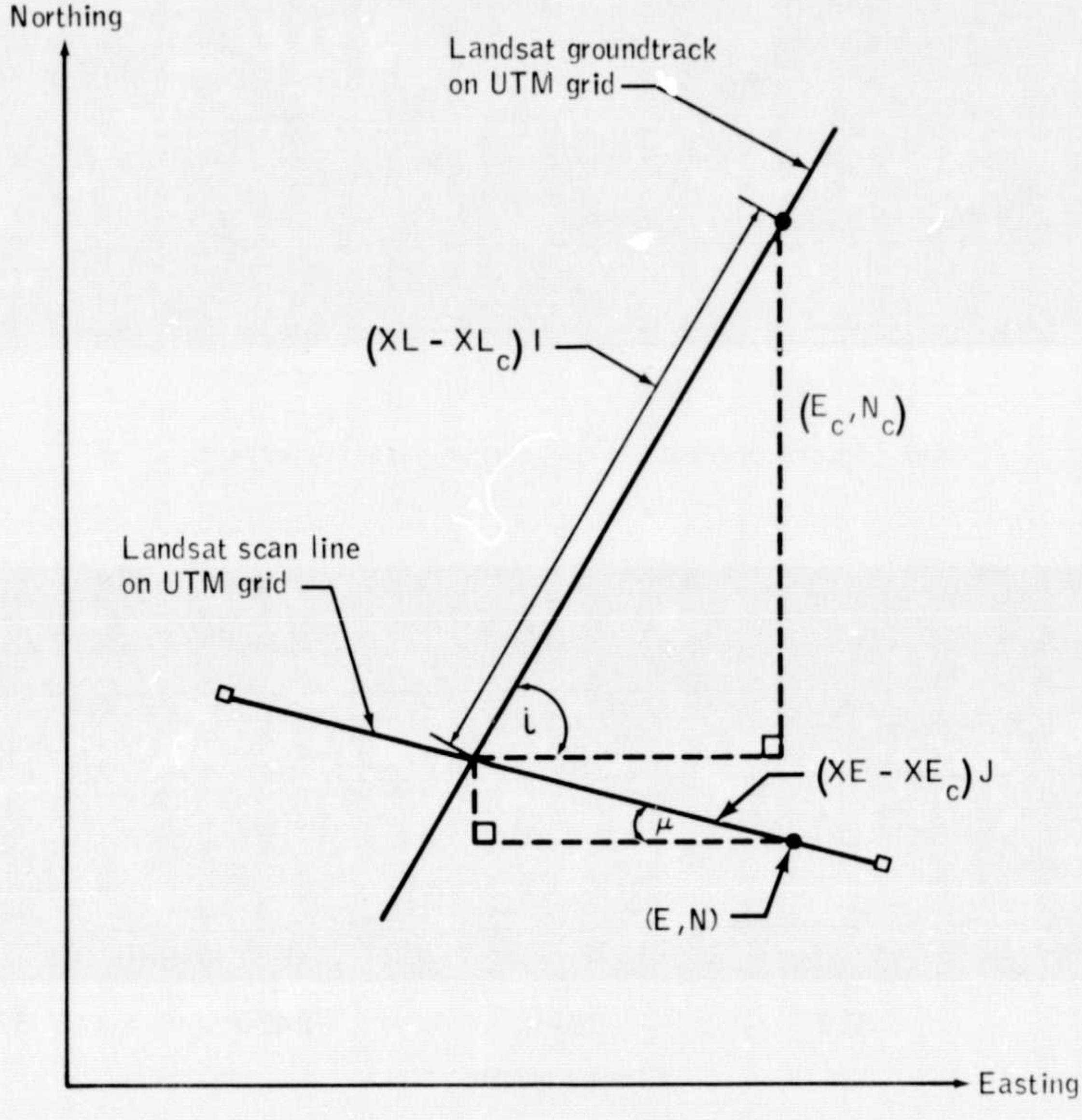


Figure 4.- Landsat geometry.

APPENDIX A

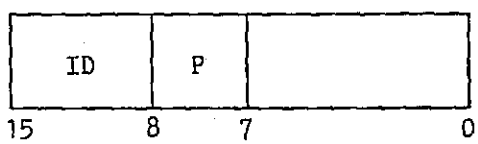
EARTH RESOURCES LABORATORY PSEUDOCOLOR TAPE

The Earth Resources Laboratory (ERL) pseudocolor tape is the ERL standard tape for displaying multispectral scanner or video data on the off-line portable image display system (PIDS). This format is also used for storing all classified data processed through the various pattern recognition systems. Data stored in this format can be recorded on the Varian 620f strip-film recorder. The format is specified in 16-bit words. Each record type has an 11-word preamble at the start of each physical record followed by the applicable video data. This tape contains logical records consisting of only one physical record.

RECORD 1 - STANDARD HEADER

The standard header record (record 1) appears only at the start of each tape and has a length of 411 16-bit words. Record 1 consists of the following.

Word	Format	Description
1	Bin	Record type identification (high-order, 8 bits = 0100_8)



where ID = 0100_8 record identity (ID)

P = bit 7, acts as a special end-of-file (EOFILE) command for the ERL-PIDS system

P = 1, command to automatically continue displaying the scan line on the PIDS

P = 0 (normal value), EOFILE command; discontinues PIDS scan-line display

Word	Format	Description
2	I	Record length (411 16-bit words)
3	I	Number of physical data records per complete scan line (i.e., the number of data or type 2 records per scan contained on this tape or contained within this edit); should equal 1
4 to 11	--	Not used (reserved for future uses)

Word	Format	Description
12 to 411	400A2	Special 800-character ID, information containing the data analysis station (DAS) input/output control console (IOCC) screen image (ASC-II, 2 characters/word); should be printed on 20 lines of 40 characters each

RECORD 2 - VIDEO DATA

The video data record (record 2) has a maximum length of 2411 16-bit words consisting of an 11-word preamble and a maximum of 2400 video data words or picture elements (pixels). Each type 2 record contains all the video data or pixels for one complete scan line and can be described as follows.

Word	Format	Description
1	Bin	Record type identification

ID	P		NO

15 8 7 4 0

where ID = 0000_8 record ID

NO = high-order scan-line digit, 10 000's digit in 4-bit code (for Landsat data, consists of the Landsat tape number, 1 to 4)

P = bit 7, acts as a special EOFILE command for the ERL-PIDS system

P = 1 (normal value), command to automatically continue displaying the scan line on the PIDS

P = 0, EOFILE command; discontinues PIDS scan-line display

Word	Format	Description
2	Bin	Scan line number; last 4 digits in 4-bit code (Note: Total scan number $\leq$99 999; the 10 000's digit (word 1) plus the remaining digits are described in the following diagram.)

1000's	100's	10's	1's

15 12 8 4 0

Word	Format	Description
3	I	Data length or number of samples (8-bit bytes) contained in the physical record (maximum number, 4800 bytes (2400 pixels))
4 to 6	3A2	Training-field name or ground-truth code (maximum of six ASC-II characters; ASC-II blanks if not used)
7 to 9	Bin	Scan-line interrange instrumentation group (IRIG) A time in 4-bit code as indicted in the following diagram (should be zeros if not used)

Day	Day	Day	Hour

15 12 8 4 0

Hour	Minute	Minute	Second

15 12 8 4 0

Second	0.1 s	0.01 s	0.001 s

15 12 8 4 0

Word	Format	Description
10	I	Start element number for entire scan line
11	I	End element number for entire scan line (Note: Both the start and end element numbers refer to the total scan line and not just to the physical record, unless a scan line of data consists of only one physical record.)
12	Bin	Pixel 1 data
13	Bin	Pixel 2 data
14	Bin	Pixel 3 data
.	.	.
.	.	.
.	.	.

Word	Format	Description
M	Bin	Pixel N data

where $N \leq 2400$ pixels (determined by taking the inclusive difference between words 11 and 10 or by dividing word 3 by word 2)

$M = N + 11$-word preamble

$M \leq 2411$ 16-bit words

Data word format, pseudocolor mode

15 – 5	5 – 0
	CODE

where CODE contains the 6-bit pseudocolor number (0 to 63)

RECORD 3 - END OF EDIT

The end-of-edit record (record 3) appears at one end of each edit or tape, has a length of 411 16-bit words, and can be described as follows.

Word	Format	Description
1	Bin	Record type identification (high-order, 8 bits = 0377_8)

15 – 8	7	0
ID	P	

where ID = 0377_8 record ID

P = bit 7, acts as a special EOFILE command for the ERL-PIDS system

P = 1, command to automatically continue displaying the scan line on the PIDS

Word	Format	Description

P = 0 (normal value), EOFILE command; discontinues PIDS scan line

2	I	Record length (411 16-bit words)
3	I	Number of physical data records per complete scan line (i.e., the number of data or type 2 records per scan contained on this tape or contained within this edit)
4 to 11	--	Not used (reserved for future uses)
12 to 411	400A2	Special 800-character ID information containing the DAS IOCC-screen image (ASC-II, 2 characters/word); should be printed on 20 lines of 40 characters each

RECORD 4 - END OF FILE

The end-of-file record (record 4) is used as a tape mark and appears after each end-of-edit record. The occurrence of two consecutive end-of-file records indicates end-of-tape.

APPENDIX B

MODULE FLOW CHARTS

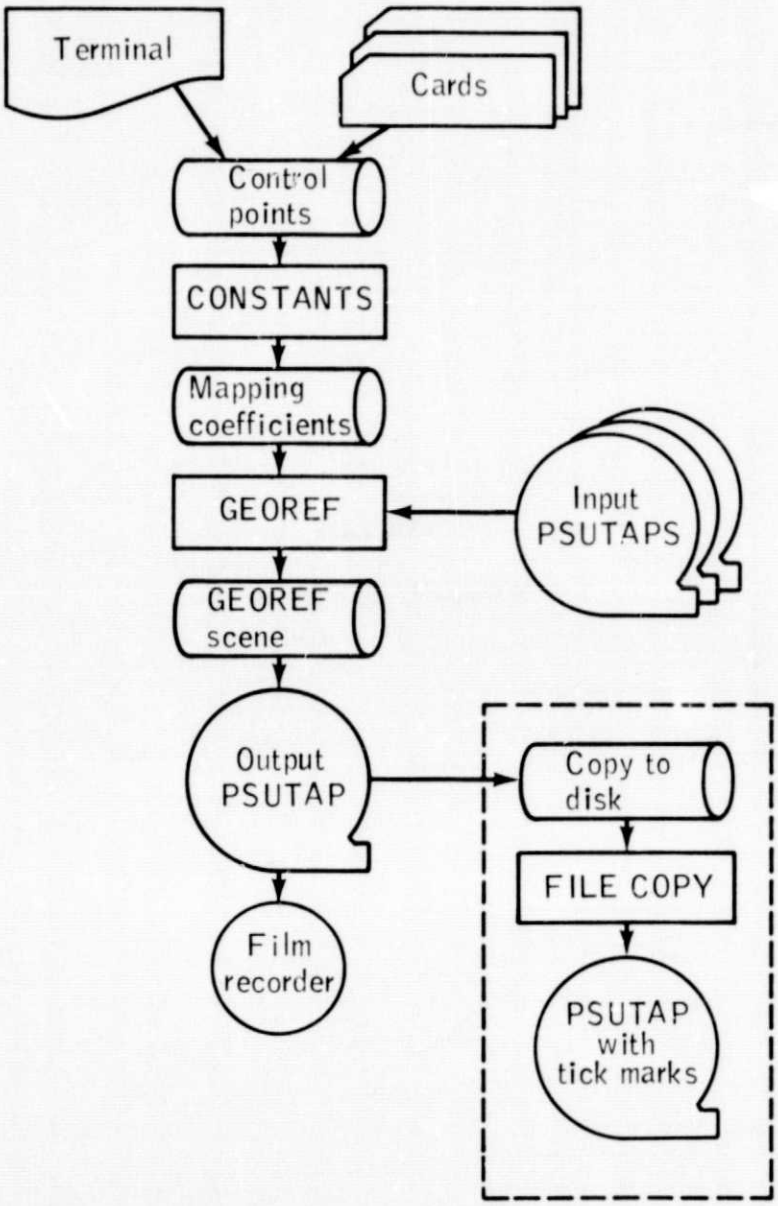


Figure B-1.- Flow diagram of the relationship among the georeferencing modules.

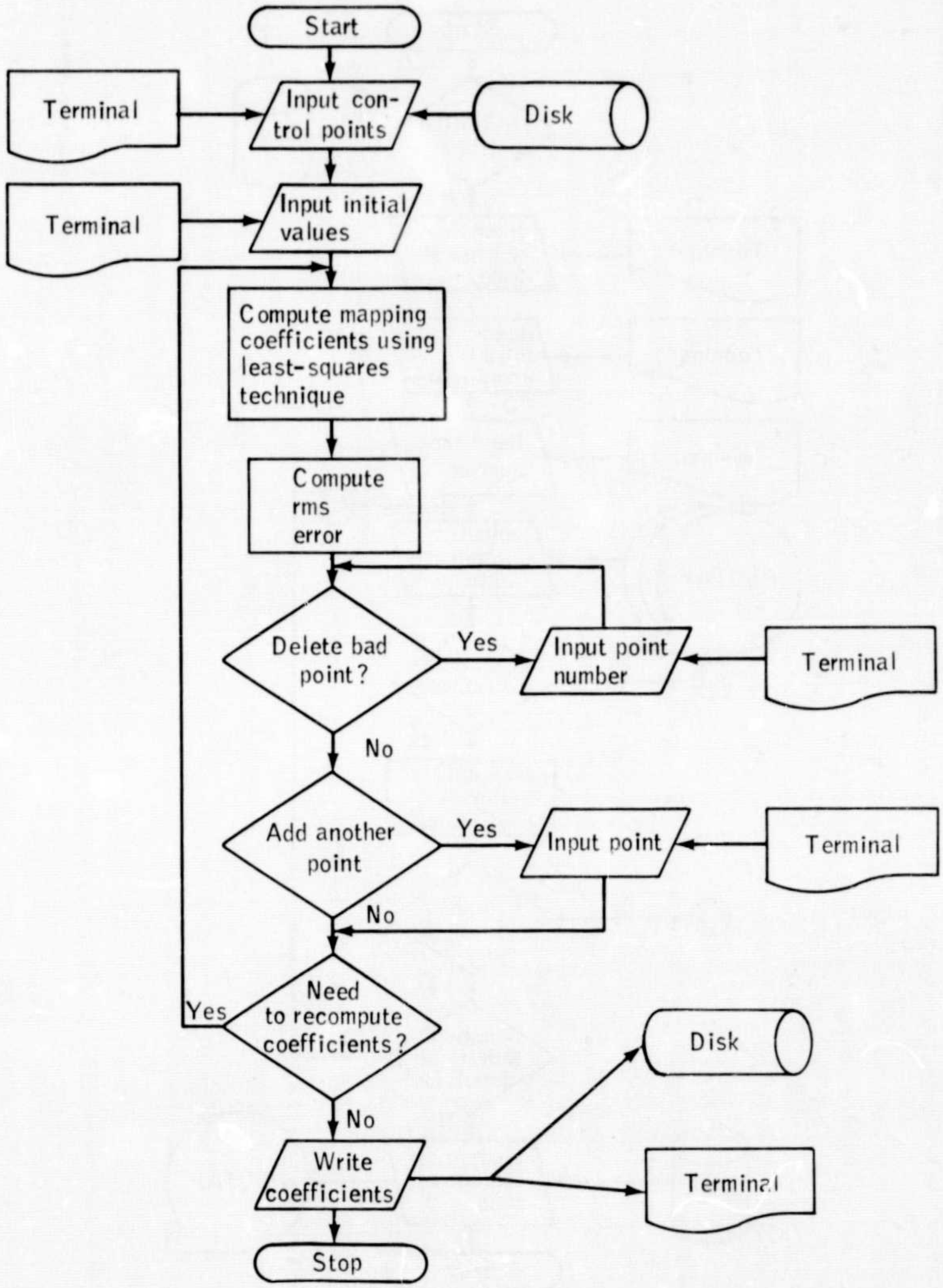


Figure B-2.- Flow chart for the module CONSTANTS.

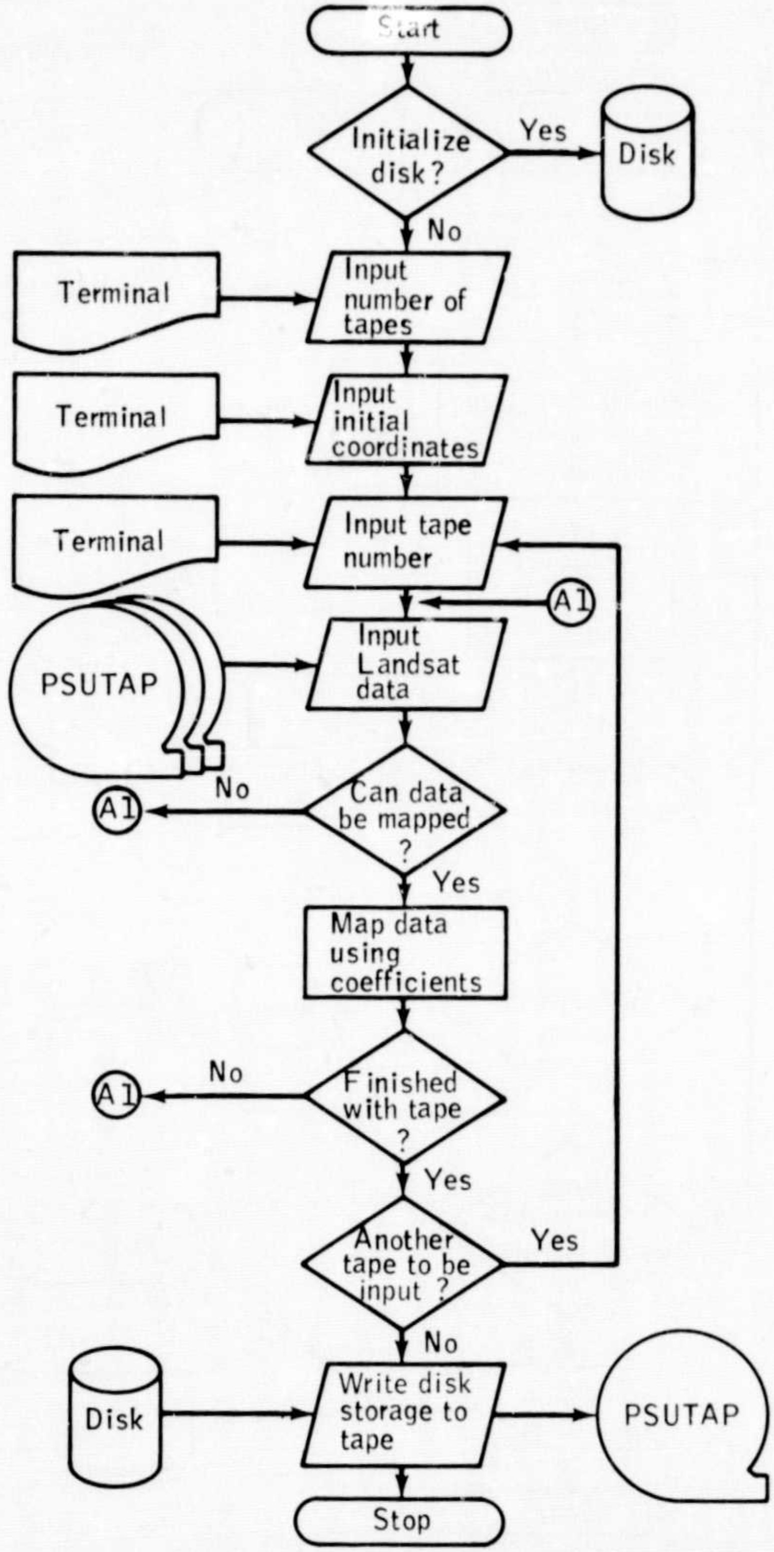


Figure B-3.- Flow chart for the module GEOREF.

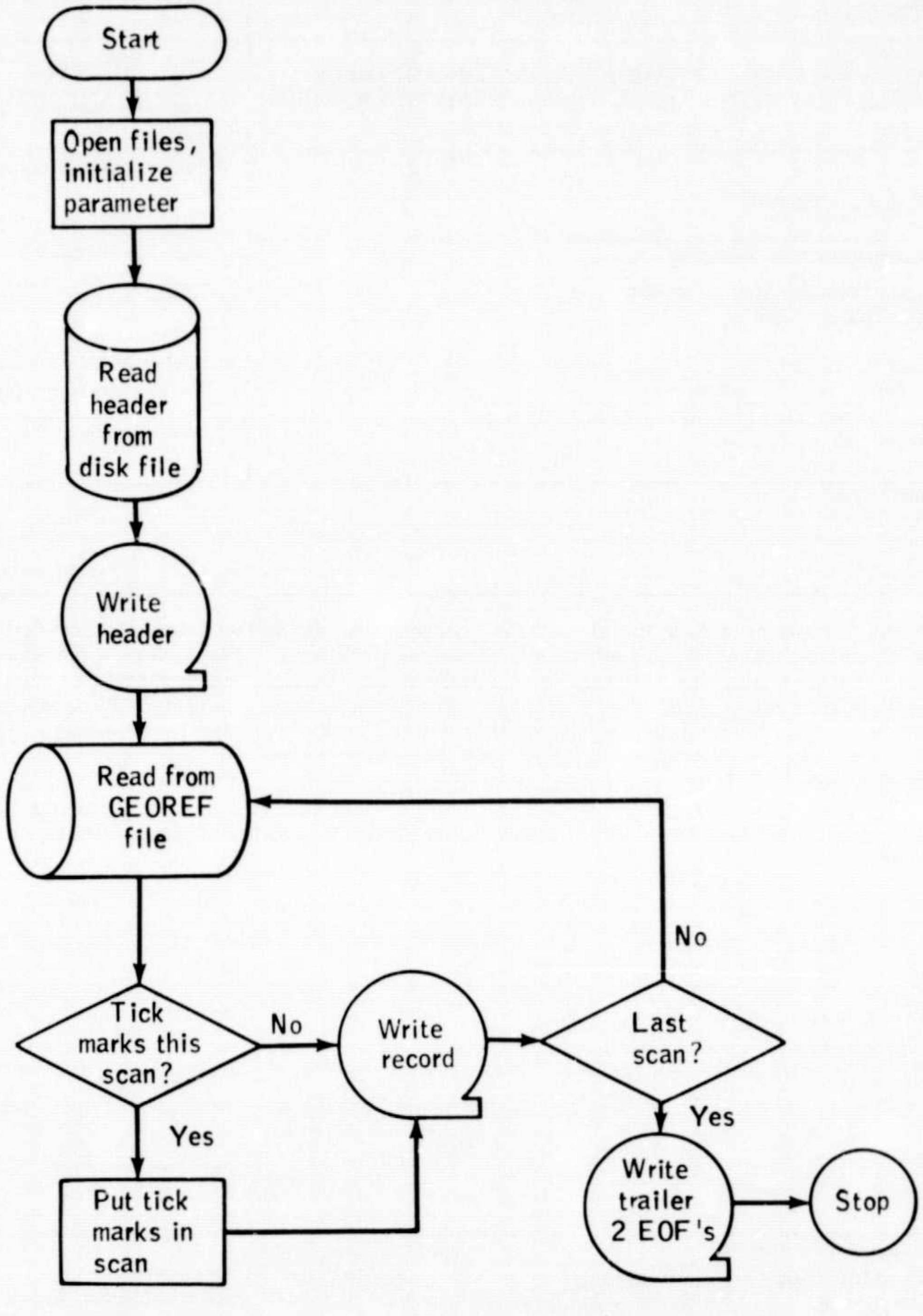


Figure B-4.- Flow chart for the module FILE COPY.

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16. Abstract

Surface classifications and pictorial (map) representations of the Earth are of more utility if such data can be related to standard geographic referencing systems. The universal transverse Mercator grid is such a geographic referencing system. The Landsat multispectral scanner system acquires data that can be used to generate surface classifications and pictorial representations of the Earth surface. The mapping equations that relate Landsat data to the universal transverse Mercator grid are, in general, quite complicated. However, almost linear approximations are reasonably accurate in local areas. Software has been written in FORTRAN IV language for Varian 70-series computer, which reformats Landsat-data-derived surface classifications and pictorial representations into a digital array that corresponds to the universal transverse Mercator grid.

17. Key Words (Suggested by Author(s)) Mercator projection; Photomapping; Earth resources; Environmental surveys; Thematic mapping; Automatic pattern recognition; Map (programing language)	18. Distribution Statement STAR Subject Category: 61 (Computer Programing and Software)

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